Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the South Bay Ocean Outfall (SBOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Treated wastewater is discharged to the Pacific Ocean via the SBOO at a depth of ~28 m and at a distance of approximately 5.6 km west of Imperial Beach. During 2008, average daily flow through the outfall was about 25 mgd. The fate of wastewater discharged into offshore waters is determined by oceanographic conditions that impact water mass movement, including horizontal and vertical mixing of the water column and current patterns. These same factors can also affect the distribution of turbidity (or contaminant) plumes that originate from various point and non-point sources. In the South Bay region these include tidal exchange from San Diego Bay, outflows from the Tijuana River north of the border and from Los Buenos Creek in Mexican waters, storm drains or other water discharges, and surface water runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions either individually or synergistically.

Because of the above, evaluations of oceanographic parameters such as water temperature, salinity, and density that determine the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975). Analysis of the spatial and temporal variability of these and other parameters (e.g., light transmittance or transmissivity, dissolved oxygen, pH, and chlorophyll) may also elucidate patterns of water mass movement. Monitoring patterns of change in these parameters for the receiving waters surrounding the SBOO can help: (1) describe deviations from expected oceanographic patterns, (2) assess the impact of the wastewater plume relative to other input sources, (3) determine the extent to which water mass movement or mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations.

The evaluation and interpretation of bacterial distribution patterns and remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of wastewater plumes (Pickard and Emery 1990, Svejkovsky 2009, also see Chapter 3 of this report). Thus, the City of San Diego combines measurements of physical oceanographic parameters with assessments of fecal indicator bacteria (FIB) concentrations and remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site.

This chapter describes the oceanographic conditions that occurred in the South Bay region during 2008. The results reported herein are also referred to in subsequent chapters to explain patterns of FIB distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected once per month at 40 fixed monitoring stations (Figure 2.1). These stations are located between 3.4–14.6 km offshore along the 9, 19, 28, 38, and 55-m depth contours, and form a grid encompassing an area of ~450 km^2 surrounding the outfall. Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth (CTD) instrument. The CTD was lowered through the water column at each station to collect

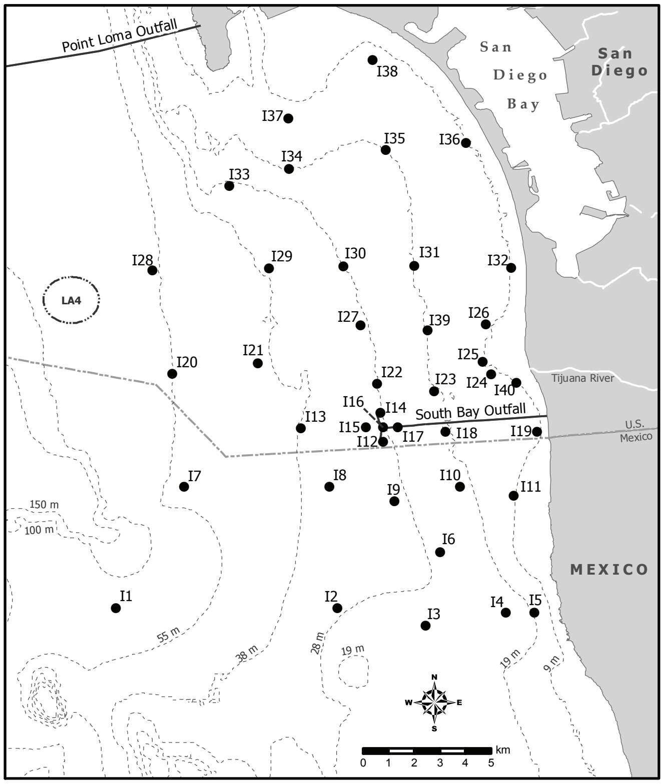

Figure 2.1
Water quality monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

continuous measurements of water temperature, salinity, density, pH, water clarity (transmissivity), chlorophyll *a*, and dissolved oxygen (DO). Water column profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the SBOO region during 2008 also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, CA (see Svejkovsky 2009). All usable images for the monitoring area captured during the year by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded, and 22 high clarity Landsat Thematic Mapper (TM) images and two Aster images were acquired. High resolution aerial images were collected using Ocean Imaging's DMSC-MKII digital multispectral sensor. The DMSC's four channels were configured to a specific wavelength (color) combination designed to maximize detection of the wastewater discharge signature by differentiating between the waste field and coastal turbidity plumes. Depth of penetration for this sensor varies between 8–15 m depending on water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Fifteen DMSC overflights were conducted in 2008, which consisted of one to five flights per month during winter when the surfacing potential was greatest for the wastewater plume (see below) and when rainfall was also greatest. In contrast, only three surveys were flown during the spring and late summer months.

Data Treatment

The water column parameters measured in 2008 were summarized by month in two different ways: (1) the mean calculated over the entire water column for each station, and (2) means calculated over all stations located along each depth contour (i.e., 9-m, 19-m, 28-m, 38-m, 55-m). In addition, mean temperature, salinity, DO, pH, and transmissivity data from 2008 were compared with historical profile plots consisting of means for 1995–2007 ± one standard deviation. Data for these historical analyses were summarized at 5-m depth increments and were limited to four quarters and four representative stations located along the 28-m depth contour. These stations included I12 located near the end of the southern diffuser leg, I9 located south of the outfall, and I22 and I27 located north of the outfall.

Results and Discussion

Climate Factors and Seasonality

Southern California weather can generally be classified into wet (winter) and dry (spring–fall) seasons (NOAA/NWS 2009a), and differences between these seasons affect certain oceanographic conditions (e.g., water column stratification, current patterns and direction). Understanding patterns of change in such conditions is important in that they can affect the transport and distribution of wastewater, storm water, or other types of turbidity plumes that may arise from various point or non-point sources. Winter conditions typically prevail in southern California from December through February during which time higher wind, rain, and wave activity often contribute to the formation of a well-mixed or relatively homogenous (non-stratified) water column, and can decrease surface salinity (Jackson 1986). The chance that the wastewater plume from the SBOO may surface is highest during such times when there is little, if any, stratification of the water column. These conditions often extend into March as the frequency of winter storms decreases and the seasons begin to transition from wet to dry. In late March or April the increasing elevation of the sun and lengthening days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In October or November, cooler temperatures associated with seasonal changes in isotherms, reduced solar input, along with increases in stormy weather, begin to cause the return of well-mixed or non-stratified water column conditions.

Total rainfall in 2008 was just over 12 inches in the San Diego region, which exceeded the historical average (NOAA/NWS 2009b). Rainfall followed expected seasonal storm patterns, with the greatest and most frequent rains occurring during the winter and fall months (Figure 2.2A). Air temperatures were generally similar during the year to historical values, although exceptions occurred in October and November (Figure 2.2B).

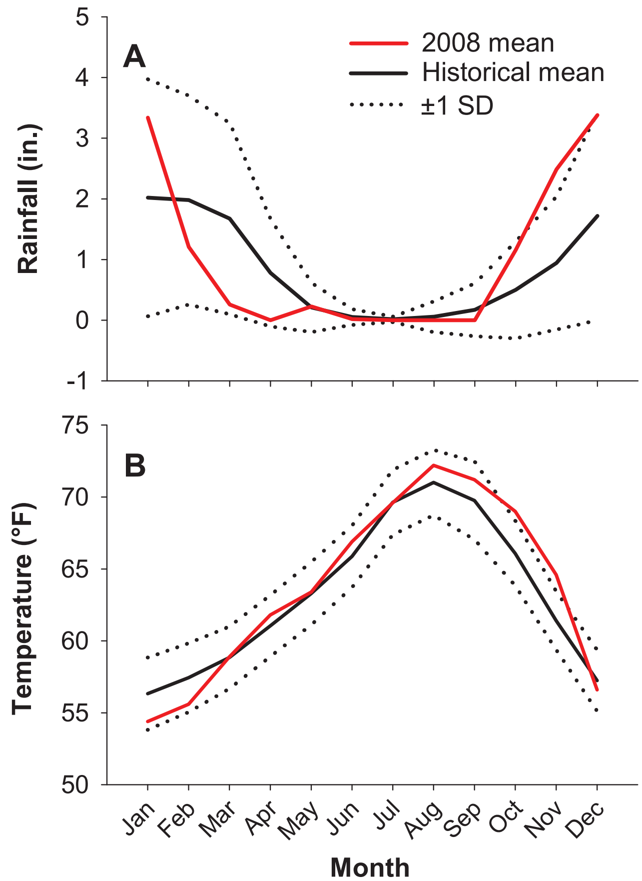

Figure 2.2
Comparison of rainfall (A) and air temperatures (B) at Lindbergh Field (San Diego, CA) for 2008 compared to historical levels. For 2008, rainfall data are expressed as total inches per month, whereas temperature data are monthly averages. Historical rainfall and temperature data are expressed as monthly means ± one standard deviation for the period 1914 through 2007.

Ocean Current Observations

Although assessment of ocean currents is not presently required by the Monitoring and Reporting Program specified in the NPDES permit for the South Bay outfall region (see Chapter 1), relevant information is available for 2008 from two different studies. These special studies include a) the remote sensing project conducted by Ocean Imaging for the IBWC and City of San Diego as mentioned previously (see Svejkovsky 2009), and b) a separate project conducted for the IBWC utilizing HF Radar and AUV technologies (see Terrill et al. 2009). Below is a summary of some of the major observations from these projects.

Results from aerial imagery indicated that the direction of current flow in surface waters was predominantly southward in 2008, although occasional northward flows occurred following

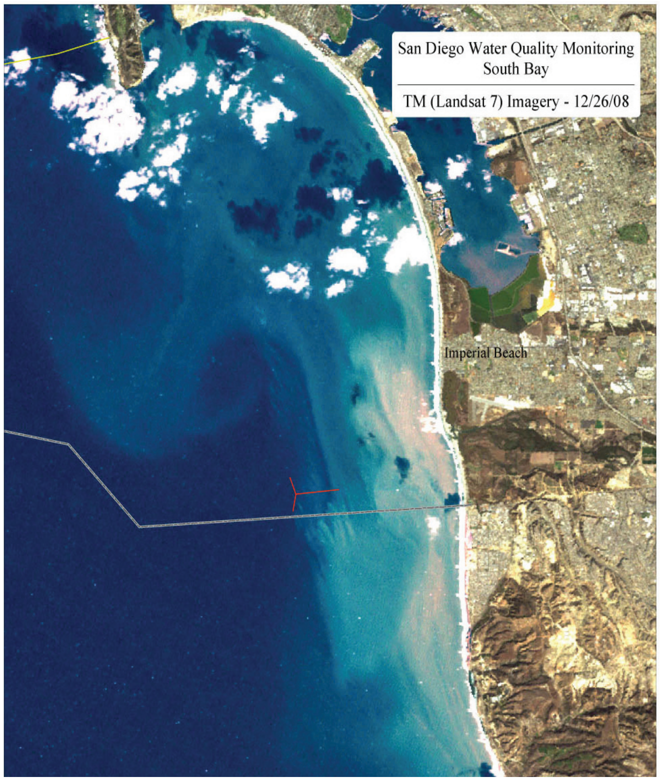

Figure 2.3
TM imagery showing the San Diego water quality monitoring region, acquired on December 26, 2008. A strong northerly current can be seen carrying a sediment turbidity plume along the shore from Los Buenos Creek (Mexico) to Imperial Beach following a rain storm.

storm events (Svejkovsky 2009). For example, the remote sensing observations indicated that increased flows from the Tijuana River during the wet season resulted in large northward-flowing turbidity plumes that extended along the coast as far north as Imperial Beach and Coronado (Figure 2.3). These plumes were often associated with increases in FIB contamination along the shoreline or in nearshore waters (see Chapter 3). These findings are generally consistent with more detailed observations on current flow through the study area measured by Terrill et al. (2009) from January 2008 until mid-November 2008. During this approximately 11-month period, these authors also reported that the major direction of currents over most depths in the vicinity of the outfall was either in a south-southeast or north-northwest direction. Current flows to the south were slightly more frequent than those moving to the north during the summer months. In addition, coincident with periods of strong stratification during the summer, subsurface currents were more likely to shear to an easterly direction as depth increased. During the winter months currents typically moved in a southern direction with fewer northward flowing currents than in the summer. Shearing of the currents during the winter when waters were relatively well mixed was not evident.

Oceanographic Conditions in 2008

Water Temperature

In 2008, mean surface temperatures across the entire SBOO region ranged from 13.4°C in February to 20.8°C in August, while bottom temperatures averaged from 9.6°C in June to 16.0°C in December (Table 2.1). Water temperatures varied by depth and season, with no discernable patterns relative to wastewater discharge (Appendix A.1). As expected, bottom temperatures decreased with depth, with up to a 5.2°C difference between the 9-m and 55-m depth contours. In contrast, surface waters were slightly cooler inshore during 11 months of the year (February–December), with up to a difference of 1.6°C between the 9-m and 55-m depth contours. The lowest temperatures of the year occurred between March and June at the bottom depths of the deeper stations, which probably reflected spring upwelling in the area.

Temperature is the main factor affecting the density and stratification of southern California ocean waters (Dailey et al. 1993, Largier et al. 2004), and differences between surface and bottom temperatures can provide the best indication of surfacing potential for wastewater plumes. This is particularly true for the shallow waters of the SBOO region. During 2008, thermal stratification of the water column generally followed normal seasonal patterns. For example, the water column was least stratified during the winter and late fall (e.g., January–February, November–December) at the 28-m offshore stations (Figure 2.4). In contrast, waters were most stratified from July through August. These patterns were similar to those reported by Svejkovsky (2009) using remote sensing methods and by Terrill et al. (2009) using moored thermistor arrays. For example, the

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the SBOO region during 2008. Values are expressed as means for each month pooled over all stations along each depth contour.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)													
9-m	Surface	13.6	13.4	14.2	14.8	16.6	15.2	19.1	20.2	18.9	17.0	17.1	16.6
	Bottom	13.3	12.9	12.4	11.3	14.0	11.8	13.8	14.7	15.2	14.8	15.9	16.0
19-m	Surface	13.6	13.4	14.1	14.2	16.5	15.3	18.0	20.0	18.5	16.9	17.1	16.5
	Bottom	12.9	12.4	11.1	10.5	11.8	10.8	12.2	13.1	14.5	13.3	14.9	14.8
28-m	Surface	13.7	13.4	13.7	14.6	16.4	15.2	18.8	20.8	19.4	17.0	17.3	16.4
	Bottom	12.4	12.1	10.9	10.3	11.2	10.2	11.7	12.6	13.5	12.9	14.7	13.9
38-m	Surface	13.5	13.6	14.1	15.0	16.8	15.7	19.1	20.7	19.7	17.7	16.8	16.8
	Bottom	11.7	11.8	10.7	10.3	10.5	10.0	11.3	12.0	13.3	12.7	13.4	12.9
55-m	Surface	13.5	13.6	14.3	15.1	16.8	16.8	19.2	20.7	20.1	17.9	17.3	16.9
	Bottom	11.1	11.0	10.3	10.2	10.4	9.6	11.0	11.5	12.6	12.0	13.5	12.9
Salinity (ppt)													
9-m	Surface	33.44	33.41	33.52	33.72	33.84	33.75	33.61	33.55	33.43	33.38	33.36	33.32
	Bottom	33.48	33.52	33.60	33.83	33.87	33.81	33.61	33.51	33.42	33.29	33.36	33.38
19-m	Surface	33.45	33.40	33.53	33.74	33.81	33.73	33.62	33.53	33.36	33.38	33.37	33.33
	Bottom	33.52	33.57	33.71	33.87	33.83	33.84	33.61	33.45	33.41	33.27	33.37	33.39
28-m	Surface	33.43	33.44	33.53	33.68	33.79	33.75	33.61	33.53	33.43	33.40	33.36	33.34
	Bottom	33.55	33.58	33.76	33.90	33.85	33.86	33.62	33.42	33.43	33.28	33.38	33.37
38-m	Surface	33.46	33.44	33.51	33.65	33.75	33.75	33.61	33.58	33.41	33.41	33.35	33.36
	Bottom	33.65	33.60	33.83	33.93	33.87	33.88	33.65	33.51	33.43	33.30	33.43	33.39
55-m	Surface	33.43	33.45	33.51	33.60	33.72	33.73	33.60	33.55	33.45	33.45	33.38	33.38
	Bottom	33.78	33.80	33.96	33.99	33.88	34.01	33.69	33.62	33.48	33.39	33.43	33.42
Dissovled Oxygen (mg/L)													
9-m	Surface	8.3	8.5	8.0	8.8	9.2	8.8	9.0	9.2	9.0	8.1	8.1	8.0
	Bottom	7.7	7.0	6.1	5.2	7.3	5.8	6.6	8.3	8.1	7.9	7.3	7.3
19-m	Surface	8.5	8.5	8.1	9.0	9.0	9.1	9.7	9.2	9.1	8.3	8.3	8.2
	Bottom	7.0	5.9	4.5	3.4	5.3	4.4	5.7	7.9	8.4	7.7	7.4	7.3
28-m	Surface	8.7	8.4	7.8	9.2	8.6	8.4	9.6	9.0	9.2	8.3	8.5	8.0
	Bottom	6.1	5.6	4.1	3.4	4.4	3.5	5.6	7.6	7.8	7.4	7.4	7.1
38-m	Surface	8.6	8.7	8.4	9.1	8.3	7.8	9.4	8.6	8.9	8.4	8.4	8.2
	Bottom	4.9	5.1	3.4	3.3	3.5	3.3	5.2	6.7	7.7	7.3	6.5	6.6
55-m	Surface	8.7	8.6	8.7	8.9	8.1	8.0	9.2	8.0	8.4	8.3	8.3	8.1
	Bottom	3.8	4.1	2.9	2.9	3.7	3.2	4.8	5.6	6.5	6.6	6.6	6.5

Table 2.1 *continued*

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH													
9-m	Surface	8.1	8.2	8.1	8.2	8.3	8.2	8.2	8.3	8.2	8.2	8.1	8.1
	Bottom	8.1	8.0	8.0	8.0	8.1	7.9	8.0	8.2	8.0	8.2	8.0	8.1
19-m	Surface	8.2	8.2	8.2	8.2	8.3	8.2	8.3	8.2	8.2	8.2	8.1	8.1
	Bottom	8.1	8.0	7.8	7.9	7.9	7.8	7.9	8.2	8.1	8.1	8.0	8.0
28-m	Surface	8.2	8.2	8.1	8.3	8.3	8.2	8.3	8.3	8.2	8.2	8.2	8.1
	Bottom	8.0	7.9	7.8	7.9	7.8	7.8	7.9	8.1	8.1	8.1	8.0	8.0
38-m	Surface	8.2	8.2	8.2	8.2	8.3	8.2	8.3	8.2	8.2	8.3	8.1	8.1
	Bottom	7.9	7.9	7.8	7.8	7.8	7.8	7.9	8.0	8.0	8.1	8.0	7.9
55-m	Surface	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8.2	8.1	8.3	8.1	8.1
	Bottom	7.8	7.8	7.7	7.8	7.8	7.8	7.8	7.9	7.9	8.0	8.0	7.9
Transmissivity (%)													
9-m	Surface	72	58	64	76	62	63	73	73	63	80	74	70
	Bottom	60	52	64	73	67	71	76	74	73	77	67	64
19-m	Surface	80	72	74	76	71	60	76	75	63	85	82	84
	Bottom	71	74	77	82	80	80	86	82	80	83	78	71
28-m	Surface	82	82	78	77	77	66	79	78	68	87	85	82
	Bottom	79	84	85	86	84	87	89	87	85	88	81	82
38-m	Surface	81	80	79	78	76	77	82	79	71	88	86	85
	Bottom	85	84	82	88	89	88	90	89	87	89	89	87
55-m	Surface	82	83	80	82	81	79	84	88	79	89	89	90
	Bottom	85	88	88	88	90	90	90	89	89	90	90	91
Chlorophyll *a* (µg/L)													
9-m	Surface	4.8	8.5	5.5	7.3	19.9	18.8	7.5	8.5	10.4	3.8	4.7	5.5
	Bottom	7.7	7.4	6.8	23.0	14.2	11.2	9.8	13.4	10.9	6.8	6.7	5.1
19-m	Surface	3.6	4.9	3.7	7.8	7.0	19.2	5.1	4.5	8.1	2.6	2.8	4.4
	Bottom	4.9	3.2	3.1	7.0	7.9	7.3	4.0	7.8	7.4	7.5	3.0	3.2
28-m	Surface	3.8	3.1	3.4	4.9	4.4	14.5	4.6	3.3	5.5	1.9	1.8	5.6
	Bottom	3.0	1.7	1.9	2.0	5.6	3.7	2.4	5.0	4.9	5.3	2.8	2.1
38-m	Surface	3.1	3.8	3.2	4.0	5.2	7.4	1.7	2.0	5.4	1.0	1.8	3.3
	Bottom	1.2	1.5	1.1	1.4	2.6	2.9	2.1	1.9	3.7	4.7	1.1	1.2
55-m	Surface	4.8	4.1	6.1	3.8	3.8	6.4	2.4	1.3	3.7	1.3	1.6	2.0
	Bottom	0.5	0.6	0.4	1.1	1.7	0.5	1.2	1.3	1.8	1.5	1.1	1.1

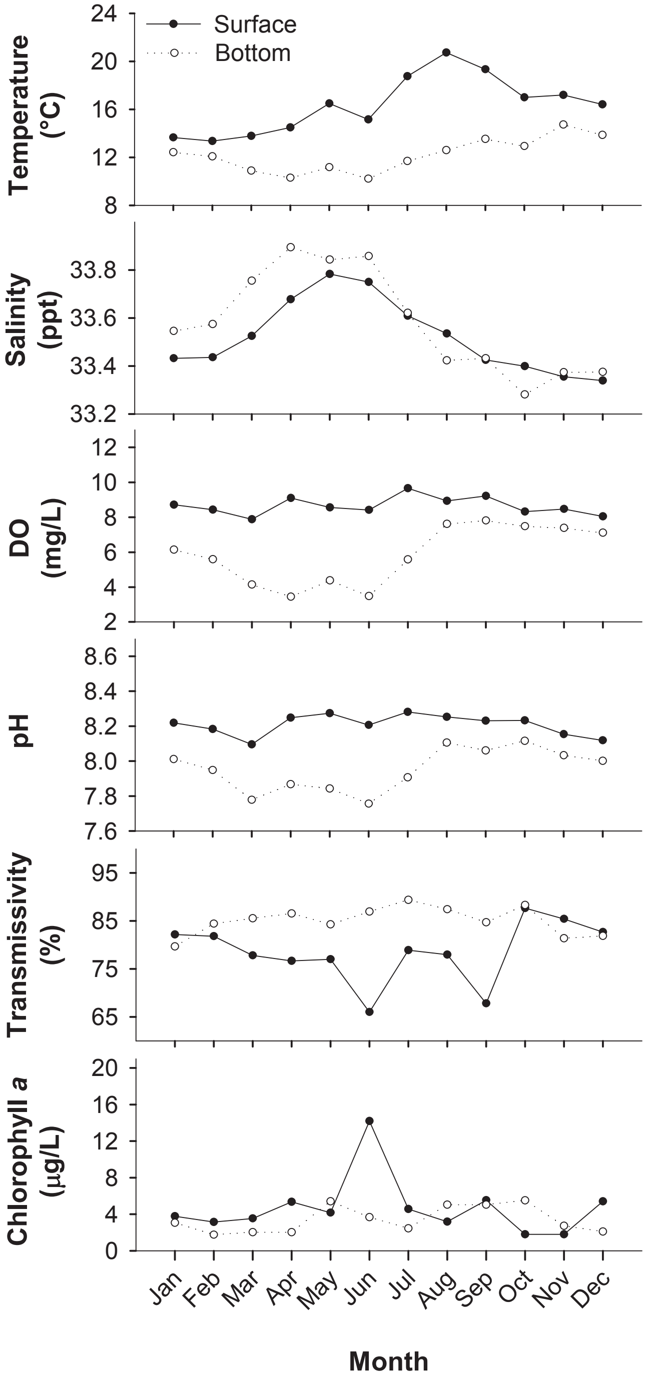

Figure 2.4

Summary of the oceanographic conditions in the South Bay region during 2008: Temperature, Salinity, Dissolved Oxygen (DO), pH, Transmissivity, and Chlorophyll *a*. Values are expressed as monthly averages at the 28-m SBOO stations pooled over surface (≤2m) and bottom (≥25m) depths.

periods mentioned above correspond to months when DMSC aerial imagery detected the near-surface signature of the SBOO wastewater plume above the terminus of the outfall's southern diffuser leg (e.g., see Figure 2.5). Subsequent aerial imagery suggested that the waste field, as usual, remained deeply submerged from late April to October when the water column was stratified (see Svejkovsky 2009).

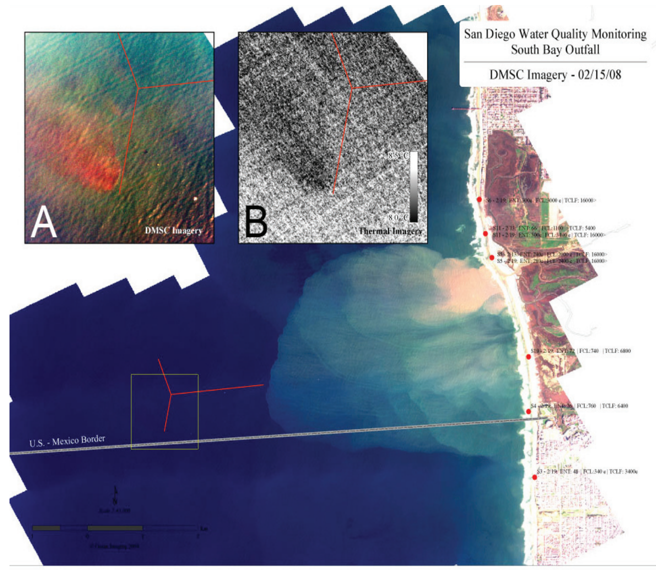

Figure 2.5

DMSC image composite of the SBOO outfall and coastal region acquired on February 15, 2008. Effluent from the south diffuser leg is seen in the inset as (A) a red plume and (B) an infrared image where darker shades of gray indicate colder water. The plume is flowing northwest.

Salinity

Average salinities ranged from a low of 33.32 ppt in December to 33.84 ppt during the previous May in surface waters, and from 33.27 ppt in October to 34.01 ppt in June at bottom depths (Table 2.1). As with temperature, salinity values demonstrated no trends relative to the wastewater discharge site (Appendix A.1). Instead, salinity followed normal seasonal patterns, with values peaking between March and June, and followed by a steady decline thereafter (see Figure 2.4). The highest salinities tended to co-occur with the lowest water temperatures, which may be indicative of some upwelling in the region during the spring months.

Density

Seawater density is a product of temperature, salinity, and pressure, which in the shallower coastal waters of southern California is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, changes in density typically mirror those in water temperatures. This relationship was true in the South Bay region during 2008 (Appendix A.1). The differences between surface and bottom water densities during the year resulted in a pycnocline that started in March and extended through October, with maximum density stratification occurring in August.

Dissolved Oxygen and pH

DO concentrations averaged from 7.8 to 9.7 mg/L in surface waters and from 2.9 to 8.4 mg/L in bottom waters (Table 2.1). Mean pH values ranged from 8.1 to 8.3 in surface waters and from 7.7 to 8.2 in bottom waters. Fluctuations in DO and pH levels followed normal seasonal patterns, and changes in concentrations appeared to co-vary with chlorophyll *a* concentrations indicative of seasonal plankton blooms. Changes in pH patterns were closely linked to changes in dissolved oxygen since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Stratification of the water column also followed normal seasonal patterns for both parameters with the greatest variations and maximum stratification occurring during the spring and early summer at the 28-m offshore stations (Figure 2.4). For DO, these low bottom water values during the spring may be due to regional upwelling as suggested by temperature and salinity data (see above). Changes in DO and pH levels relative to the wastewater discharge were not discernible.

Transmissivity

Transmissivity values were within normal ranges in the SBOO region during 2008 and there were no apparent patterns relative to wastewater discharge (Appendix A.1). Transmissivity averaged between about 51–91% over all depths during the year (Table 2.1). Additionally, water clarity was consistently greater at the offshore monitoring sites than in inshore waters, by as much as 25% at the surface and 37% at the bottom. Lower transmissivity values along the 9-m depth contour were likely due to wave and storm activity between January and March, while reductions in offshore water clarity in June co-occurred with peaks in chlorophyll *a* concentrations (i.e., phytoplankton blooms).

***Chlorophyll* a**

Mean chlorophyll *a* concentrations ranged from a low of 0.4 µg/L in bottom waters at the offshore sites during March to a high of 23 µg/L at inshore bottom depths in April (Table 2.1). The highest chlorophyll concentrations occurred at the 9-m depth contour stations between April and June, which corresponded to red tides observed at these sites. These phytoplankton blooms were likely influenced by the outflow of nutrient rich waters from local rivers (see Gregorio and Pieper 2000) and/or the upwelling of nutrient rich cool waters off the Point Loma headland and their southerly flow into the South Bay region (see Roughan et al. 2005, Terrill et al. 2009). These upwelling events and the subsequent algal blooms were visible in several MODIS images captured during the year (J. Svejkovsky, personal communication). These events were also the likely cause of at least some of the declines in transmissivity and increases in DO and pH levels that occurred during the spring months (see above). The red tides observed during the spring of 2008 were not as large as in the past, and no blooms were visible during the summer months as in previous years (e.g., see City of San Diego 2007, 2008).

Historical Assessment of Oceanographic Conditions

Water column profiles of temperature, salinity, DO, pH, and transmissivity were analyzed for four representative stations (I9, I12, I22, I27) sampled during the January (winter), April (spring), July (summer), and October (fall) monthly surveys in 2008, after which they were compared to historical profiles for 1995–2007 (Figure 2.6). Only DO and pH exceeded historical conditions in the winter of 2008, with values for both being higher than the historical mean at depths of 15 m and above. In contrast, water temperatures were lower than the historical average throughout

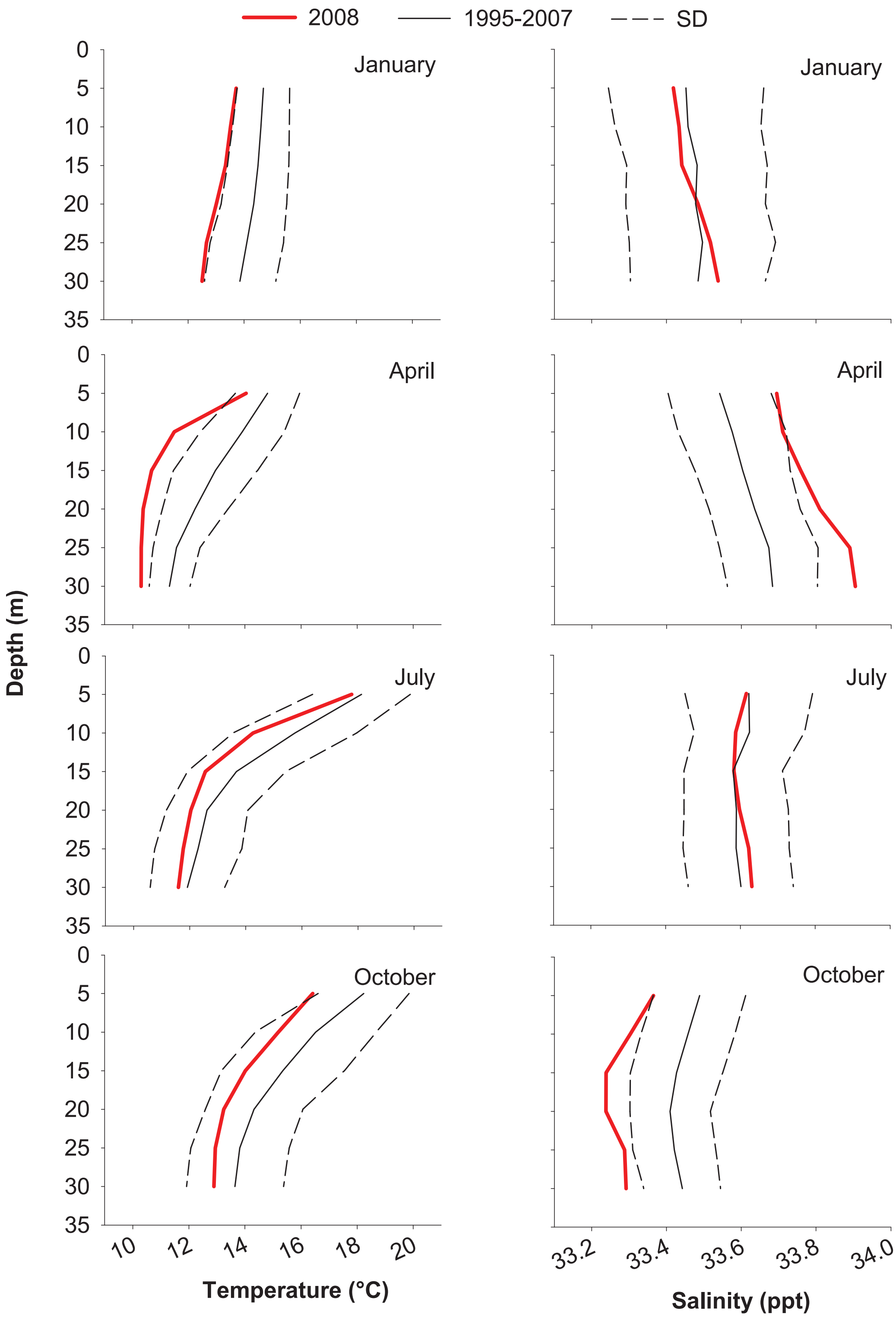

Figure 2.6

Water column temperature , salinity, dissolved oxygen, pH, and transmissivity profiles for 2008 compared to historical data for 1995–2007 at SBOO 28-m stations I9, I12, I22, and I27. Data from 2008 are monthly averages, whereas historical data represent 13-year means ± one standard deviation (SD); both are calculated for each month at 5-m depth intervals.

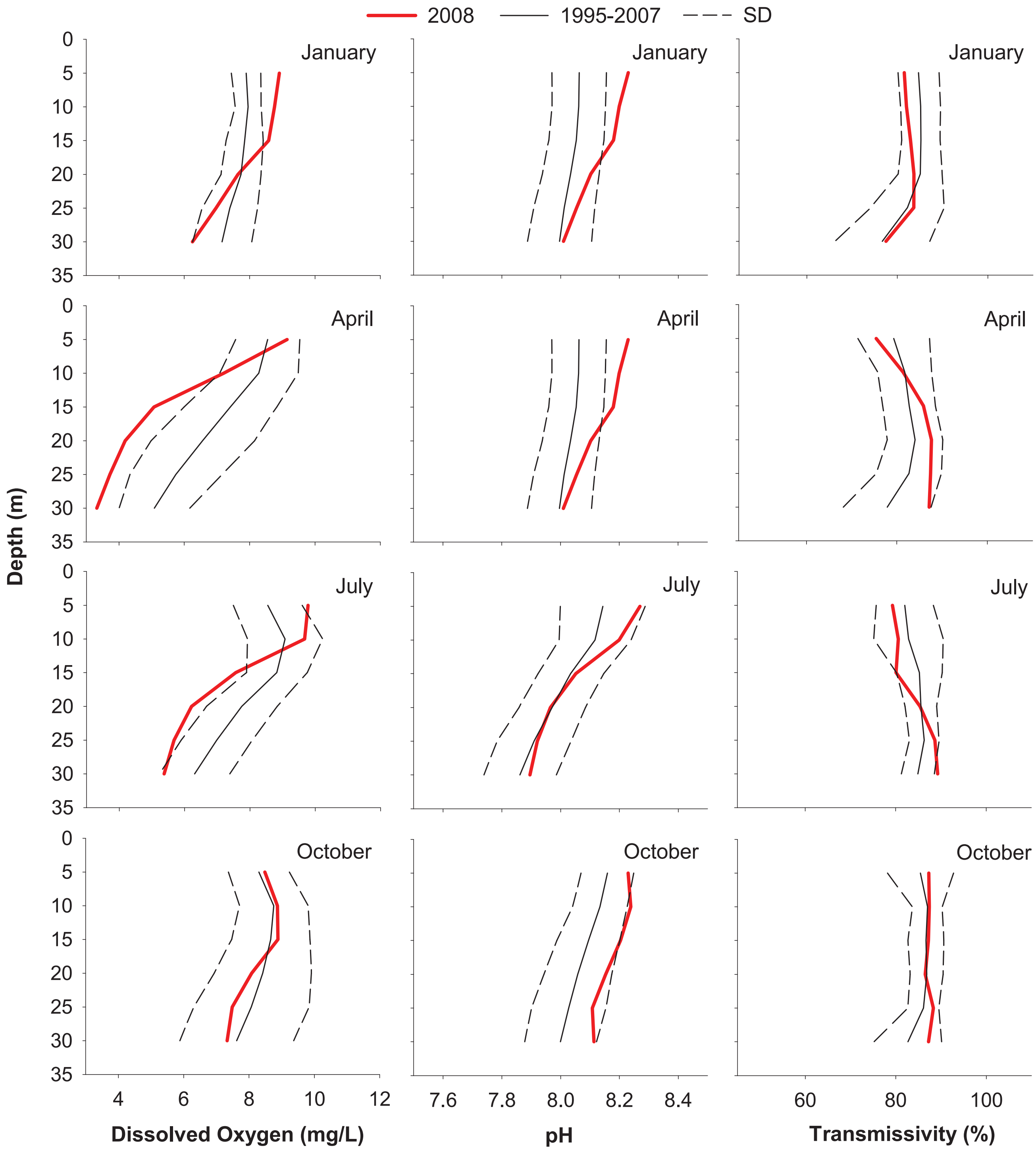

Figure 2.6 *continued*

the year. During the spring survey in April, temperature and DO were below normal at most depths, whereas salinity and pH values were higher than normal. These conditions probably reflect localized upwelling events within the region that occurred from March to June in 2008 (e.g., Svejkovsky 2009; also see previous section). During the summer, only DO values fell outside the range of historical conditions with concentrations less than normal at depths 15 m or below. Values for most parameters were within historical ranges during the fall. The only exception was for salinity, for which values were below normal at all depths.

Summary and Conclusions

The South Bay outfall region was characterized by relatively normal oceanographic conditions in 2008, which included localized upwelling and corresponding phytoplankton blooms in the spring. Upwelling events were indicated by cooler than normal water temperatures, especially at bottom depths, and higher than normal salinity from March through June. Phytoplankton blooms were indicated by high chlorophyll concentrations, which were also confirmed by aerial and satellite imagery (see Svejkovsky 2009).

No apparent relationship was observed during the year between proximity to the outfall discharge site and values of ocean temperature, salinity, pH, transmissivity, chlorophyll *a*, or dissolved oxygen. Instead, oceanographic conditions generally followed normal seasonal patterns. For example, thermal stratification followed typical patterns for the San Diego region, with maximum stratification of the water column occurring in mid-summer and reduced stratification during the winter. DMSC aerial imagery detected the signature of the wastewater plume in near-surface waters above the outfall discharge site on several occasions between January–February and November–December when the water column was well mixed. In contrast, the plume appeared to remain deeply submerged between April–October when the water column was stratified. Results from microbiology surveys further support the conclusion that the SBOO wastewater plume remained offshore and submerged during these months (see Chapter 3).

Oceanographic conditions for the SBOO region in 2008 remained notably consistent with changes in large scale patterns in the California Current System (CCS) observed by CalCOFI (Peterson et al. 2006; Goericke et al. 2007, McClatchie et al. 2008). For example, five significant events relevant to conditions in the region have affected the CCS during the last decade: (1) the 1997–1998 El Niño; (2) a dramatic shift to cold ocean conditions between 1999–2002; (3) a more subtle but persistent return to warm ocean conditions beginning in October 2002; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2003; (5) development of a moderate to strong La Niña in 2007 in conjunction with a cooling of the Pacific Decadal Oscillation (PDO). The shift in the PDO has contributed to the coldest ocean temperatures observed off the west coast since the 1950s (McClatchie et al. 2008, NOAA/Northwest Fisheries Science Center 2008, Runcie 2009). Temperature and salinity data for the South Bay region are consistent with all but the third of these CCS events; i.e., the cooler than normal conditions occurred in the region during 2005 and 2006 compared to other CCS surveys. Instead, conditions for the SBOO region during those two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were below the decadal mean (Peterson et al. 2006).

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